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CR151416

REPORT F77-09

DEVELOPMENT OF A MICROSTRIP UHF CONFORMAL ANTENNA

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18 APRIL 1977

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Lyndon B. Johnson Space Center
R&T Procurement Branch
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Report F77-09

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SUMMARY

Three low-profile, engineering models EMU antennas have been built and delivered. Final data for these antennas meet most of the electrical requirements in a 6" x 18" x 1.4" package which weighs under 2.0 lbs. Coverage data calculated at the design frequencies very nearly meets the design goal of providing a gain greater than or equal to -10 dBi over 80% of a sphere. Recommendations are made for future work directed toward producing an efficient quality design capable of operating in a space environment.



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I. INTRODUCTION

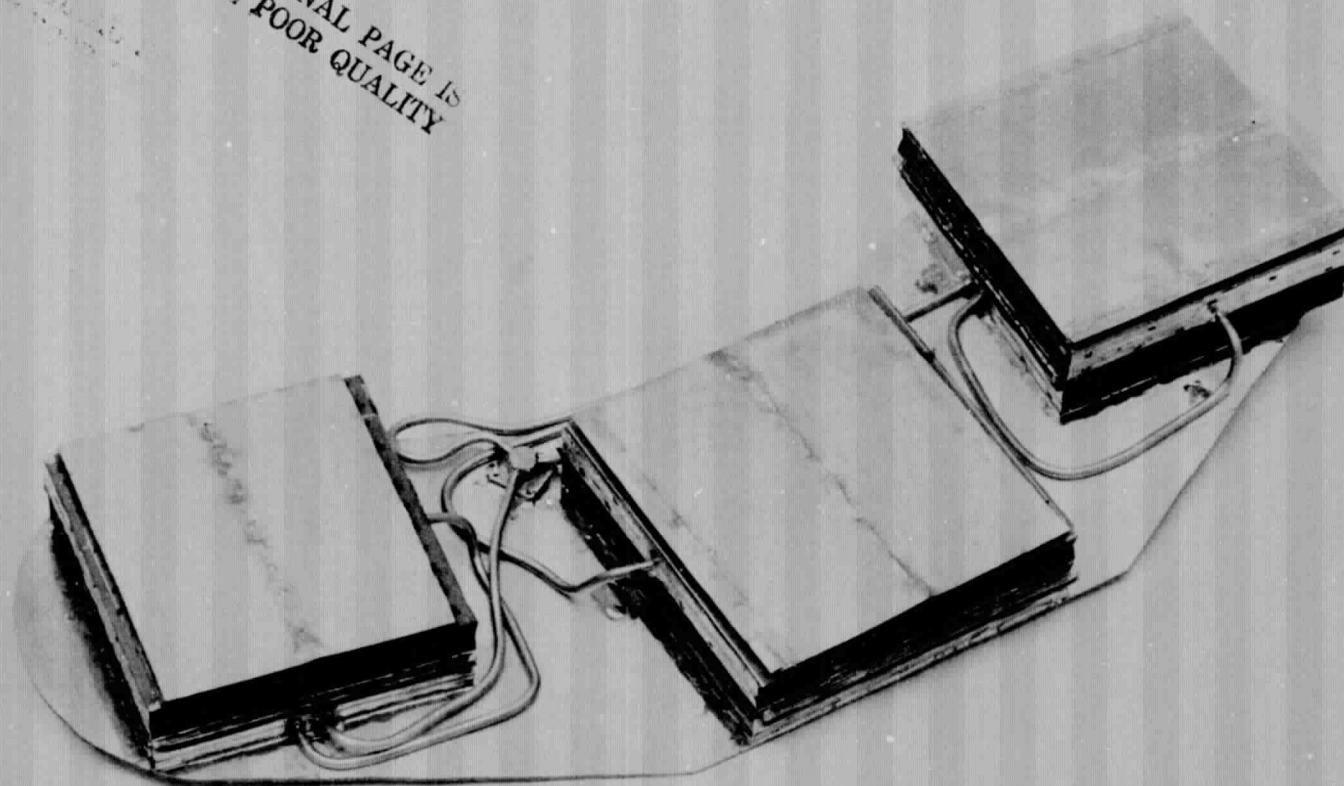
Three engineering model EMU, low-profile antennas have been produced, tested, and delivered. These state-of-the-art antennas provide an excellent example of the electrical performance that can be achieved in a low profile, electrically small antenna. Final data from these antennas meet nearly all electrical requirements of gain coverage, axial ratio, and input VSWR. Calculations show that this design will exceed the performance of the monopole antenna it is replacing, since it is nearly immune to cross-polarization effects. The gain coverage for the worst possible orientation of a linear source antenna is summarized below.

Frequency	Gain to Linear Isotropic	Coverage in % of Total Sphere
259.7	-5 dBi	46.8%
	-10 dBi	81.3%
279.0	-5 dBi	6.8%
	-10 dBi	77.7%
296.8	-5 dBi	47.2%
	-10 dBi	80.0%

This performance is achieved in an antenna that is only 6" x 18" x 1.375", with a weight of approximately 2.0 lbs shown in Figure 1.

This report reviews the development of the low-profile, UHF antenna and presents representative final data. Radiation Distribution Plots (RDP's) were taken with right hand circular and left hand circular polarization sources and the results were used to compute coverage from the best and worst case orientations of a linear source.

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Figure 1 Engineering Model EMU Antenna



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Problem areas encountered and their solutions are discussed. Finally, recommendations for future study are made. Specifically, further work is needed to fully qualify the design to survive the launch and space environment. This environment was considered in the choice of materials and construction of the antenna; however, no thermal or vibration tests were made. Further study is also recommended on methods of lower cost production. The alternative feed network designs requires further work and a study is needed to choose materials and construction techniques suitable for a protective cover.



II. SUMMARY OF DATA

A. DESIGN ALTERNATIVES STUDY

During the initial stage of this development, several approaches to the conformal UHF Antenna were tried. These approaches shared the goal of providing efficiency in a conformal, low-profile antenna. Each design was evaluated in relation to the dual-folded cavity described in the proposal. The alternate designs and the corresponding difficulties with each are described below.

1. Internal Plane Cavity Antennas

Two variations of this type antenna are shown in Figures 2a and 2b. The first of these antennas, the Floating Internal Plane Antenna, was an attempt to generate the two orthogonal linear modes in a single cavity structure. This would reduce the height of the proposed antenna. A single linear mode could not be generated in this structure and the radiation pattern was that of a monopole with a null overhead.

The second of the structures was an attempt to eliminate the monopole type mode in the cavity by grounding the top plate. However, this was unsuccessful and the radiation pattern retained the null on axis.

2. Loaded Antennas

The common method of reducing the size of an antenna using inductive or capacitive loading was also tried during this phase, Figures 3a and 3b. The first of these designs involved folding the edges of the cavity back over its top. This forms a capacitive loading of the cavity edge, reducing the size. However, the size reduction was not sufficient and this antenna was rejected.



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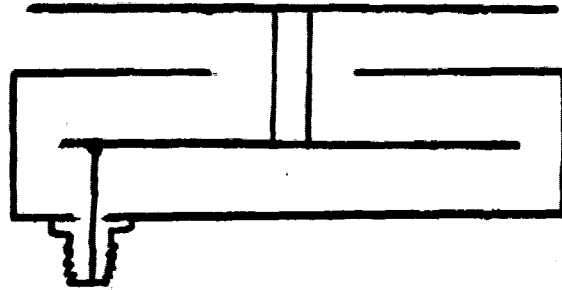


Figure 2a
Floating Internal Plane Antenna

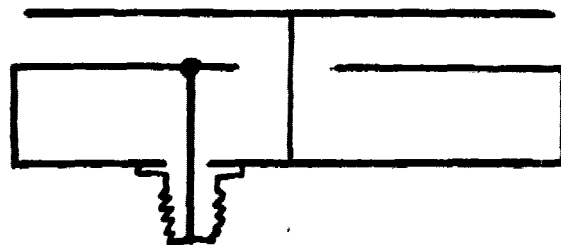


Figure 2b
Grounded Internal Plane Antenna



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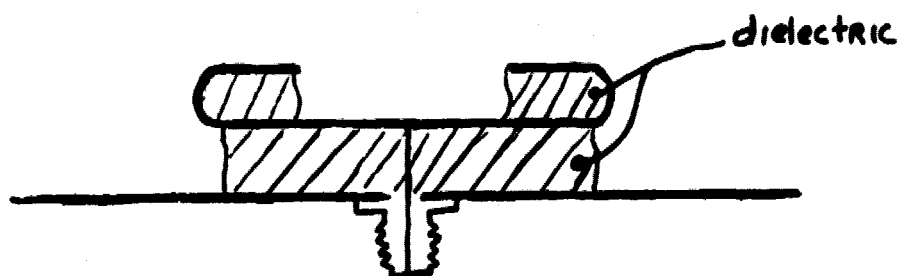


Figure 3a
Capacitively Loaded Antenna

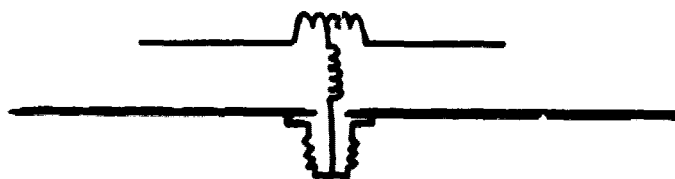


Figure 3b
Inductively Loaded Antenna



Inductive loading of the microstrip cavity was also employed as a method to reduce the size of the antenna. Two types of inductive loading were tried as shown in Figure 3b, series and shunt-to-ground. The shunt-to-ground loading produced a monopole pattern with a null. The series-loaded microstrip antenna produced a significantly smaller size; however, the efficiency was low. Both methods of inductive loading proved to be inadequate alternatives.

B. ORTHOGONALLY MOUNTED - FOLDED CAVITY DESIGN

Of all the alternative designs studied, the best efficiency and coverage was obtained with the half-wavelength folded cavity. This design was outlined in the proposal and consists of two half-wavelength cavities, each folded to have approximately 1/4 the area of the original antenna. The overall height of this antenna was reduced to half of that quoted in the proposal by using 1/8" honeycomb. Two of these linearly polarized antennas are stacked orthogonally as shown in Figure 4 and fed 90° out of phase to produce the required circular polarization.

Initial experiments with this antenna on a flat ground plane demonstrated good performance in gain and axial ratio. The size of the cavity was 4.5" x 4.5" x 1.38", and the projected weight of the total system was approximately 2.0 lbs. The feed point of the antenna was moved to obtain a 50 Ω input impedance for each of the cavities. The measured 2:1 VSWR bandwidth was approximately 2 MHz for each of the cavities.

The cavity elements were constructed with the aid of a mechanical fixture. The fixture held the .003" brass and honeycomb pieces under pressure for lamination. The fixture produced good repeatability of the elements and was designed so that simple changes would produce different cavity dimensions for resonance at other frequencies.

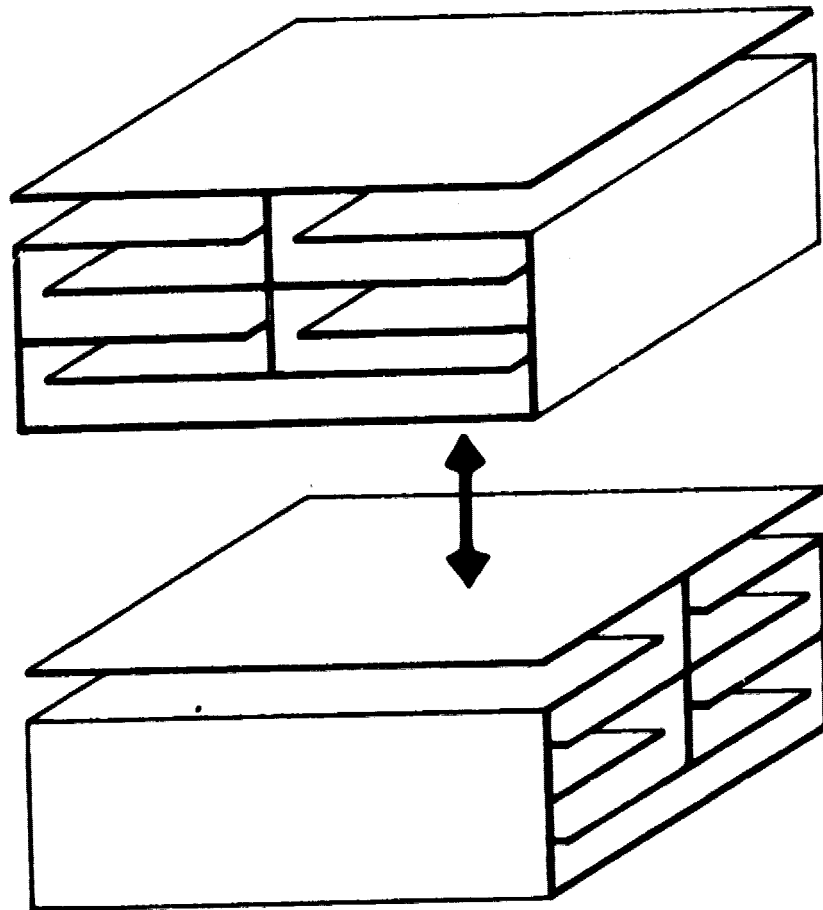


Figure 4 Stacking of Two Linearly Polarized Folded Cavities



The cavities were stacked orthogonally and mounted to a 1/16" teflon fiberglass board as shown in Figure 5. The elements were successively tuned to resonance with the antenna secured to the EMU mock-up. The 90° phasing cables were installed and the axial ratio was measured at each frequency.

Finally, lengths of matching transformer were installed. Due to the narrow bandwidth of the cavities, the response of each of the dual folded cavity elements was similar to a short circuit off resonance. Calculations demonstrated that if the proper lengths of matching transformers were used, the three antennas could be connected in parallel with no adverse effects. Optimum lengths of transformer were installed in each of the three antennas and connected together through a Triplexer to a single input connector. The input VSWR was less than 2.0:1 at each of the design frequencies (Figure 6), and the performance remained good for all antennas. Figures 7 through 9 show representative patterns using a spinning dipole source at the three design frequencies. A minor problem was observed at 279.0 MHz after installation of the Triplexer. The axial ratio increased from 2 dB to 6 dB and the gain of the antenna decreased. Since the axial ratio and gain were good before the Triplexer installation, it is believed the problem could be solved by a minor change in the length of a matching cable. However, time did not permit any iterations of the matching cables and so the problem could not be corrected. Figure 10 is a photograph of S/N002 Antenna before shipping.

C. SUMMARY OF COVERAGE DATA

A full set of Radiation Distribution Plots (RDP's) were made of antenna S/N002. A total of 6 RDP's were taken, one at each frequency with a left hand circular source and one at each frequency using a right hand circular source. The coordinate reference from the RDP's is shown in Figure 11 where $\theta = 0^\circ$ is the axis of the

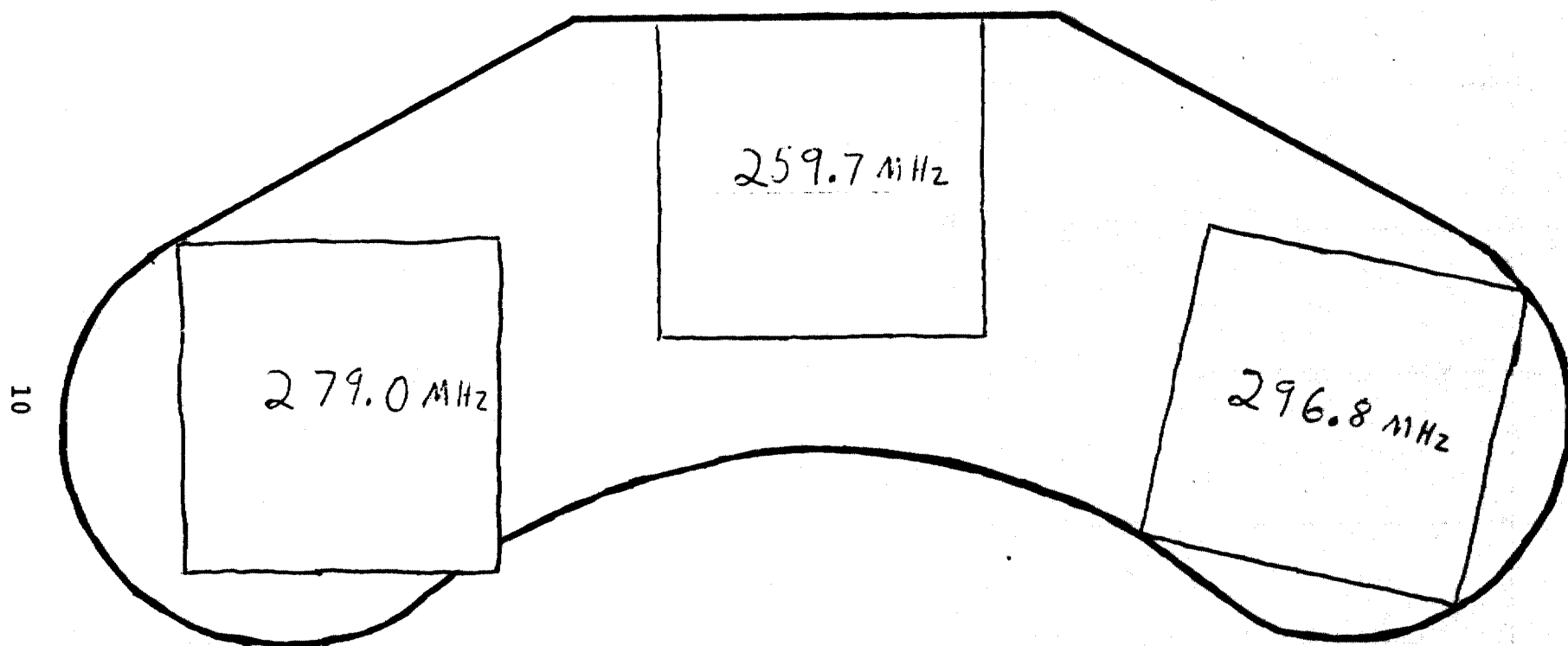


Figure 5
Mounting of Dual Cavities to Board



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PROJECT NO. 3547 PROGRAM EMU ANTENNA
PART NO. _____ MODEL NO. _____ SERIAL NO. 002
TEST TYPE: ☐ DEVELOPMENT ☐ PRE ☒ FINAL
FREQUENCY RANGE 250-300 MHz SHEET _____ OF _____

IMPEDANCE OR ADMITTANCE
COORDINATES

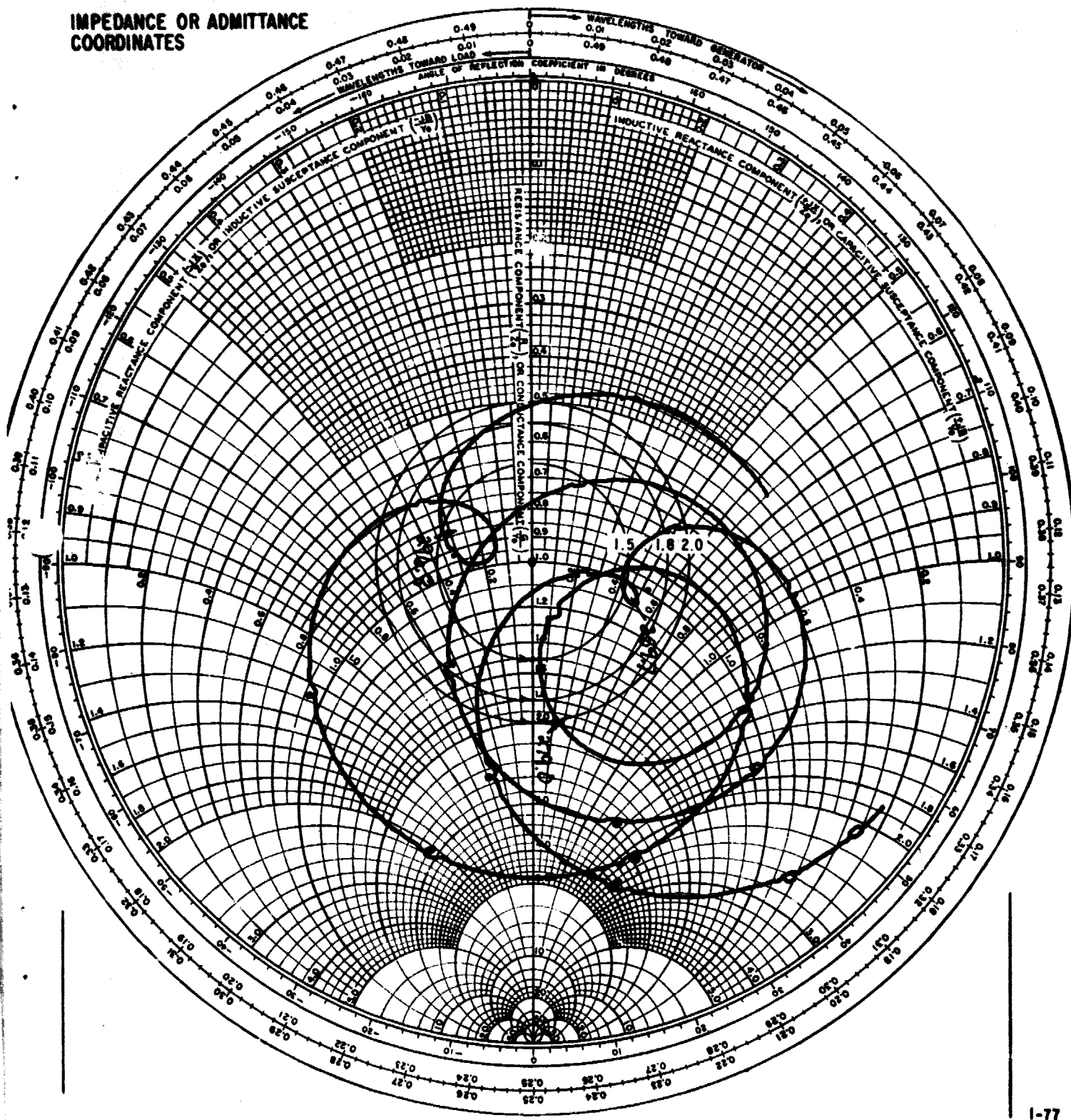


Figure 6

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REMARKS TRIPILEXER

OPER. [Signature] WITNESSED _____ DATE 3/31/77



PROJECT NO. _____ PROGRAM Backpack
 PART NO. _____ MODEL NO. _____ SERIAL NO. 003
 FREQUENCY 259.7 RANGE: ☐ LG. ☐ SM. ☐ OTHER
 TEST TYPE: ☐ DEVELOPMENT ☐ PRE ☐ FINAL
 PATTERN IN DB: _____ DB(ON CHART) = 0 DBI SHEET _____ OF _____

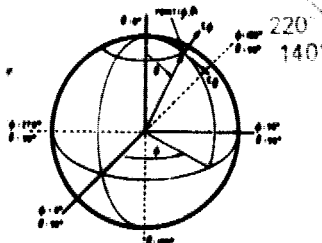
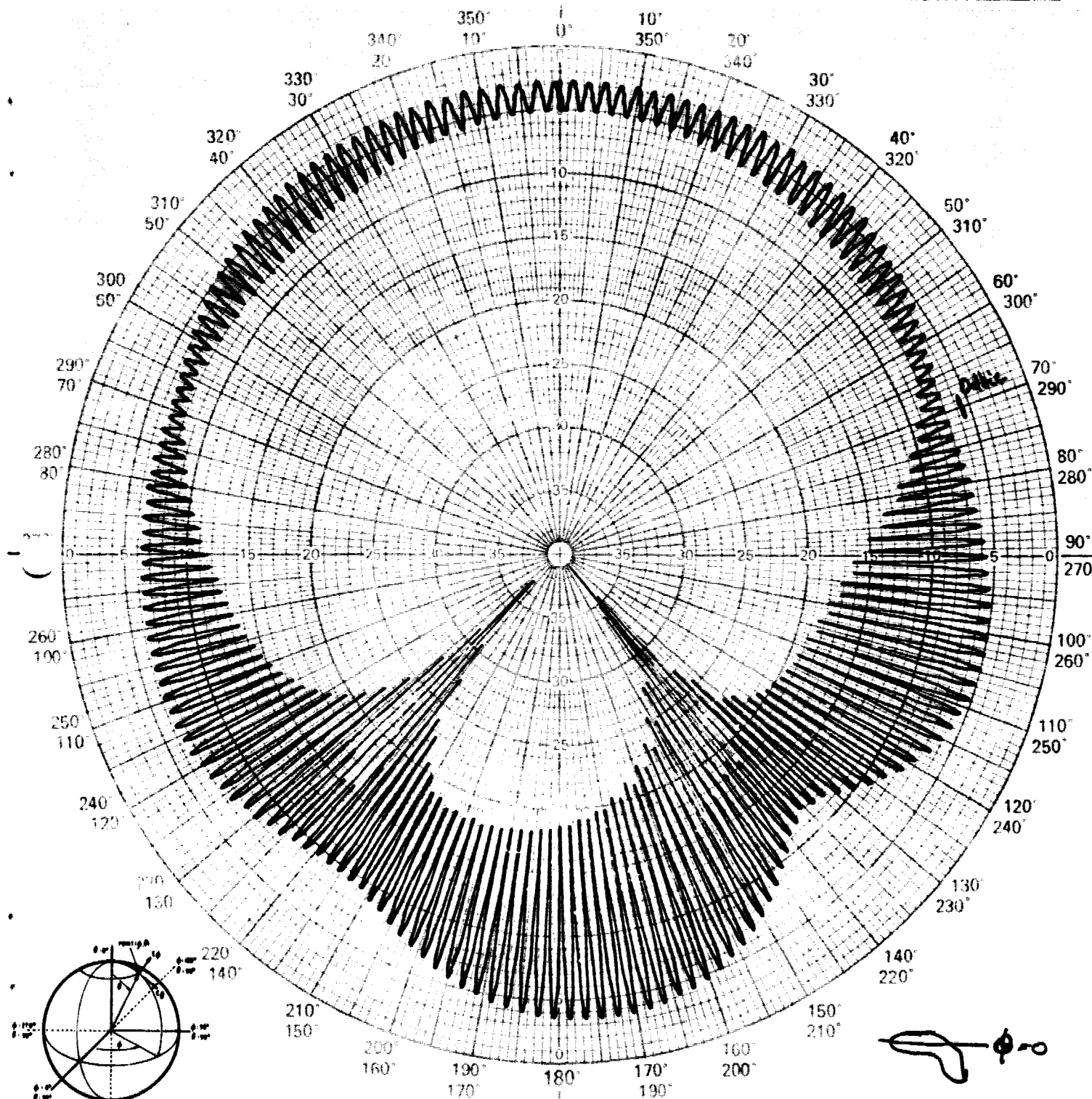


Figure 7
12

ORIENTATION

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REMARKS Final Pattern, Rotating source

POLARIZATION $E\theta$ ☐ $E\phi$ ☐ RC ☐ LC ☐
 $\phi = 0^\circ$ $\theta = 0^\circ$

OPER. JH WITNESSED _____ DATE 3/31/77



PROJECT NO. _____	PROGRAM <u>Backpack</u>
PART NO. _____	MODEL NO. _____
FREQUENCY <u>279.0</u>	SERIAL NO. <u>002</u>
TEST TYPE: ☐ DEVELOPMENT ☐ PRE ☐ FINAL	RANGE: ☐ LG. ☐ SM. ☐ OTHER
PATTERN IN DB: _____	DB(ON CHART) = <u>0</u> DBI
SHEET _____ OF _____	

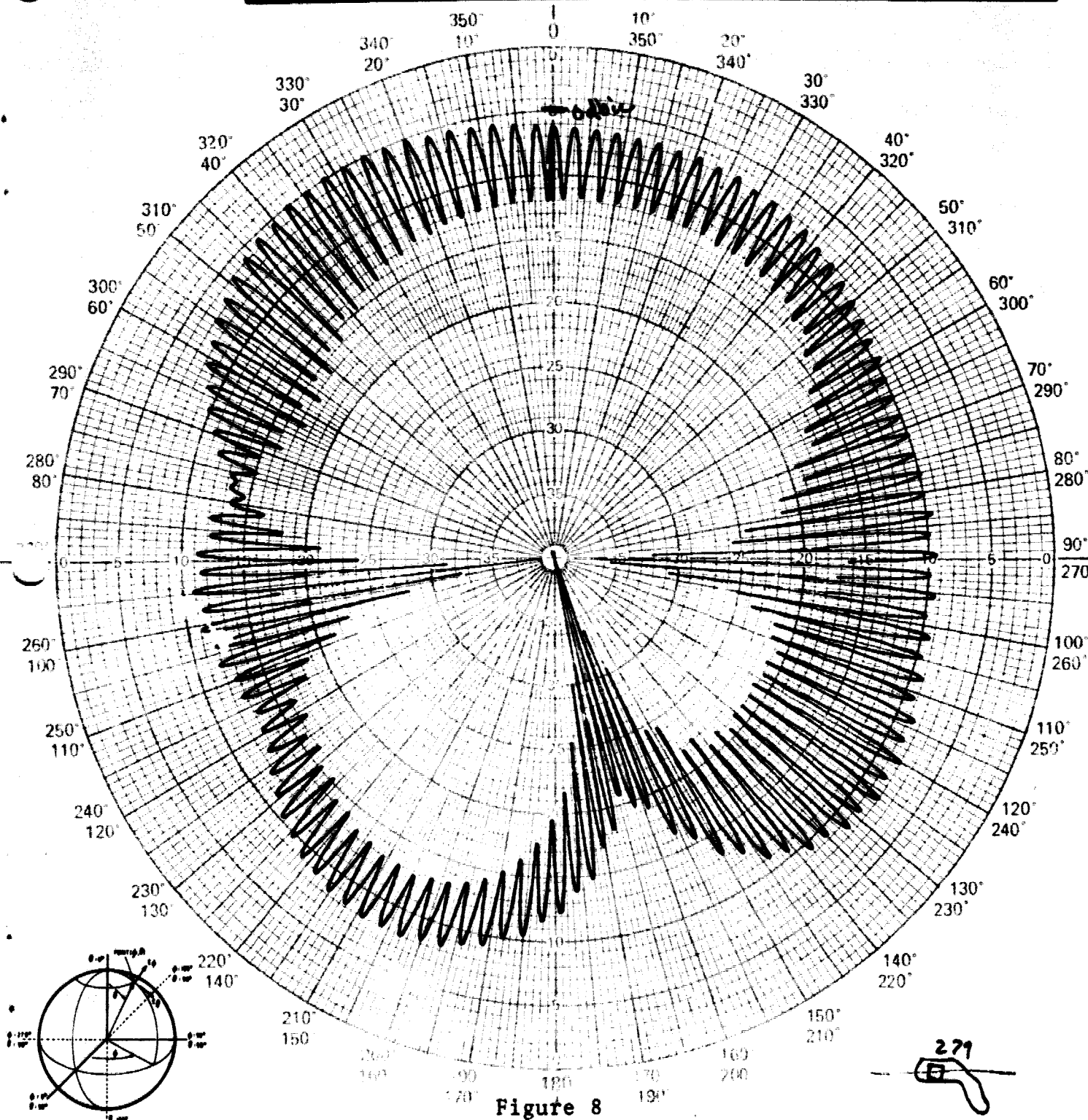


Figure 8

ORIENTATION

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REMARKS <u>Final Patterns Rotating Source</u>	POLARIZATION $\phi = 0^\circ$	$E\theta$ ☐ $E\phi$ ☐ RC ☐ LC ☐

_____	OPER. <u>Jack</u> WITNESSED <u>MS</u> DATE <u>3/24/22</u>	



PROJECT NO. _____	PROGRAM <u>Back pack</u>	SERIAL NO. <u>002</u>
PART NO. _____	MODEL NO. _____	
FREQUENCY <u>216.8</u>	RANGE: ☐ LG. ☐ SM. ☐ OTHER	
TEST TYPE: ☐ DEVELOPMENT ☐ PRE ☐ FINAL		
PATTERN IN DB: _____	DB(ON CHART) = 0 DBI	SHEET _____ OF _____

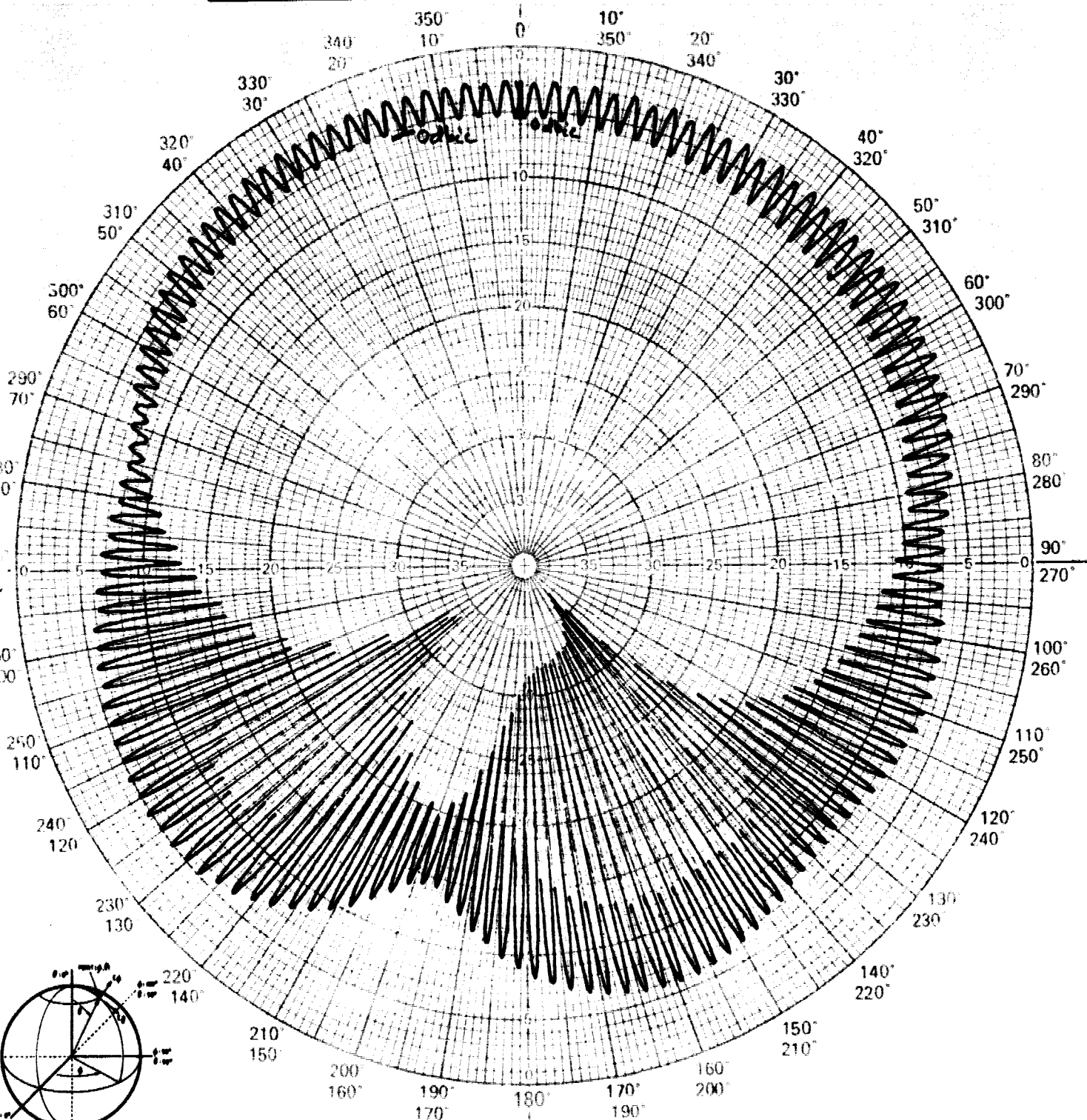


Figure 9

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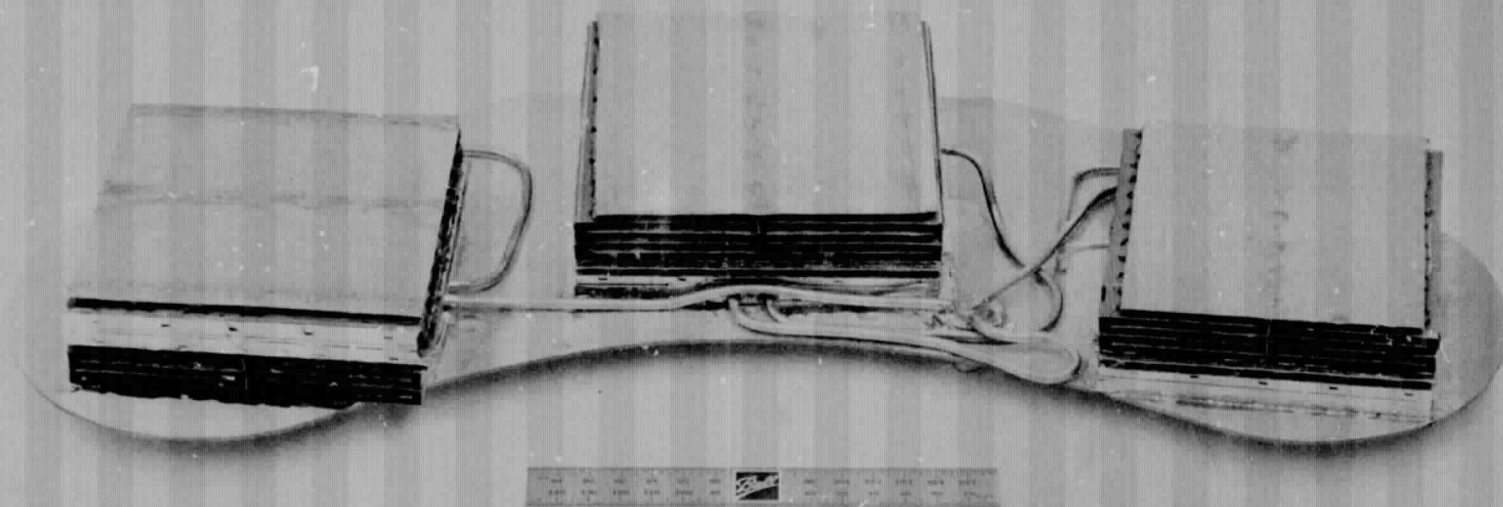
ORIENTATION

BALL BROTHERS RESEARCH CORPORATION

REMARKS Final patterns, POT

POLARIZATION $E\theta$ ☐ $E\phi$ ☐ RC ☐ LC ☐
 $\phi = 0$ $\theta =$

OPER. JACK WITNESSED MS DATE 3/31/72



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Figure 10 S/N002 Engineering Model Antenna



EMU model and the angle ϕ is defined in Figure 12. Pattern measurements are made every 2° in both angular coordinates for $0^\circ \leq \theta \leq 180^\circ$ and $0^\circ \leq \phi \leq 360^\circ$. The measurements are recorded on magnetic tape and available for computation. In particular Table 1 summarizes the coverage in percent of a total sphere at a given gain relative to circular isotropic. The computer coverage data for a RHC source demonstrates that the requirement of 80% coverage at -10 dBic is nearly met at all frequencies. The only frequency at which this requirement is not met is 279.0 MHz. It was previously mentioned that a minor problem in the Triplexer caused the gain of this antenna to be reduced. Therefore, this antenna will also meet this requirement once the matching cable lengths are optimized.

In actual application, this antenna system will be required to operate with a linear transmitting antenna on the space shuttle. Therefore, a calculation of the coverage from a single circular polarization does not completely specify the response. The radiation pattern may be linearly polarized in some region causing a potential for complete loss of signal due to cross-polarization effects. However, if the response of the antenna to both circular polarizations is known, the axial ratio may be calculated and the maximum and minimum received signal from a linear antenna may be determined. Since the response from both circular polarizations at every angle is known from the RDP data, it was a simple task to compute the coverage for the best and worst possible orientations of a linear transmitting antenna. The formula used for this computation was derived by Hatkin¹,

¹ Hatkin, L., Proceedings of the IRE, Vol. 38, No. 12
pg. 1455, December, 1950.



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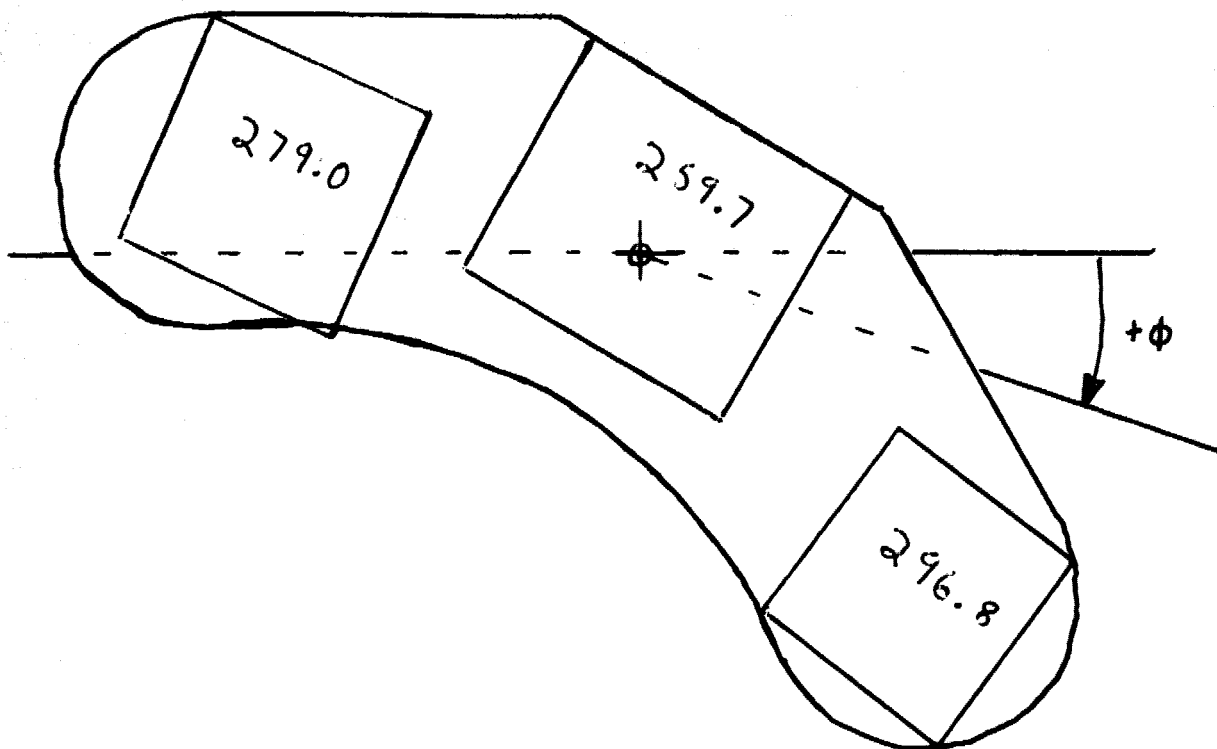


Figure 12
Angular Reference for RDP



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Table 1

Coverage in Percent of Total Sphere
For RHC Source

Gain Relative to Circular Isotropic	Percent of Sphere		
	259.7MHz	279.0MHz	296.8MHz
0 dB	7.7%	0.0%	14.6%
-2 dB	23.7%	0.0%	30.4%
-4 dB	46.8%	7.9%	47.6%
-6 dB	65.0%	28.6%	66.0%
-8 dB	78.7%	54.8%	81.8%
-10 dB	87.7%	70.0%	89.6%
-12 dB	92.3%	77.5%	93.7%
-14 dB	95.6%	83.0%	95.9%
-16 dB	97.7%	87.4%	97.4%



$$P = R_1^2 R_2^2 + L_1^2 L_2^2 + 2R_1 R_2 L_1 L_2 \cos 2\alpha$$

where $R_2 = L_2 = \frac{1}{\sqrt{2}}$, the amplitude of the circular polarizations from a linear antenna

and R_1, L_1 are respectively the amplitude components of the right hand and left hand response.

and $\alpha = 0^\circ$ for the best orientation

$\alpha = 90^\circ$ for the worst orientation

Therefore;
$$P_{\max} = 20 \log \left(\frac{R_1 + L_1}{\sqrt{2}} \right)$$

$$P_{\min} = 20 \log \left| \frac{R_1 - L_1}{\sqrt{2}} \right|$$

where $R_1 = \sqrt{P_R}$ and $L_1 = \sqrt{P_L}$

P_R is Power Response from RHC source

P_L is Power Response from LHC source

Tables 2 through 4 summarize the coverage data for the maximum and minimum response to a linear source. The gain levels are in dB relative to a linear isotropic antenna since that was the assumed source in the formulas.



Table 2

Coverage in Percent of Total Sphere
For Linear Polarization at 259.7 MHz

Gain Relative to Linear Isotropic	Percent of Sphere	
	Best Orientation	Worst Orientation
0 dB	8.7%	0.0%
-2 dB	74.6%	1.5%
-4 dB	99.1%	35.1%
-6 dB	100.0%	56.7%
-8 dB	↓	71.7%
-10 dB		81.3%
-12 dB		88.2%
-14 dB		92.5%
-16 dB		94.7%
-18 dB		97.8%
-20 dB		98.2%



Table 3

Coverage in Percent of Total Sphere
For Linear Polarization at 279.0 MHz

Gain Relative to Linear Isotropic	Percent of Sphere	
	Best Orientation	Worst Orientation
0 dB	0.0%	0.0%
-2 dB	22.7%	0.0%
-4 dB	71.7%	0.1%
-6 dB	97.2%	22.6%
-8 dB	99.7%	62.7%
-10 dB	100.0%	77.7%
-12 dB	↓	85.9%
-14 dB		91.1%
-16 dB		93.8%
-18 dB		96.4%
-20 dB		97.6%



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Table 4

Coverage in Percent of Total Sphere
for Linear Polarization at 296.8 MHz

Gain Relative to Linear Isotropic	Percent of Sphere	
	Best Orientation	Worst Orientation
0 dB	13.6%	0.0%
-2 dB	65.8%	9.4%
-4 dB	96.6%	37.1%
-6 dB	99.9%	59.2%
-8 dB	100.0%	71.2%
-10 dB	↓	80.0%
-12 dB		87.4%
-14 dB		92.4%
-16 dB		95.1%
-18 dB		97.6%
-20 dB		98.0%



III. PROBLEM AREAS AND SOLUTIONS

The first and most significant of the problems encountered was obtaining a good axial ratio at 279.0 MHz. The first antenna had a poor axial ratio at this frequency and it could not be improved by tuning the antenna. Initial experiments quickly eliminated problems with either the top or bottom cavities or the phasing cable. The hypothesis that the problem was due to cross-polarized radiation from the EMU mockup was verified with a simple experiment using a linear cavity on the mockup. The 279.0 MHz antenna was reoriented on the board to produce a good axial ratio on frequency.

A second minor problem occurred in the use of microstrip transmissions lines for phasing and matching. The advantages of low weight and ease of obtaining any impedance were attractive; however, these were outweighed by the difficulty of folding the lengthy transmission lines on the board and the long etching time between iterations. Semi-rigid coaxial cable was the simple solution to this problem. The characteristic impedances required for matching and phasing were easily obtainable and the cables could be routed on the board to cross over each other, unlike microstrip lines. The resulting triplexed antennas worked well with the coaxial cables.

A third problem which has already been mentioned was the small performance degradation at 279.0 MHz after the Triplexer installation. This degradation is believed related to incorrect matching transformer lengths in the Triplexer. Optimum lengths would have been used if time had permitted iterations in the design. However, schedule commitments and the advantage of a single input connector outweighed the minor degradation in performance at this frequency.



IV. RECOMMENDATIONS FOR FUTURE STUDY

The antennas designed and produced under this contract met nearly all electrical and mechanical specifications or goals. The computed coverage data demonstrate that this antenna should be a desirable replacement for the current whip since it is a low-profile, light-weight antenna that has low susceptibility to cross-polarization problems. The main concern of this development was to design and build an engineering model antenna that met the electrical specifications in the smallest volume for a weight of approximately 2.0 lbs. Materials and construction techniques were chosen with regard to survivability in the launch and space environment. However, extensive thermal design was not done on these engineering models and further work is required in this area. It is now necessary to qualify this design to survive in the space environment.

Present methods of assembling the folded cavity are costly in terms of time. Further study is required to improve the construction techniques before production of this antenna can be considered. Materials and techniques can be improved to reduce time and cost of assembly. Development is required to simplify the design and optimize the choice of materials for a lower cost production unit.

The feed system of the antenna also warrants further development. A tradeoff study should be made on possible methods of feeding the cavities. The advantages and disadvantages of the single feed for the antenna must be compared with those of three feeds. A small amount of work also remains to be done to optimize the present Triplexer design to eliminate the axial ratio and gain problems at 279.0 MHz.

Finally, a suitable protective radome must be chosen for the antenna. The material and construction should be shockproof



and able to survive the extremes in temperature and vacuum. The radome should be designed to offer the antenna protection from meteorite damage and some thermal isolation. A study is necessary to choose the best material and construction techniques to maintain the electrical performance and protect the antenna.